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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

STANDARD METHODS FOR MEASURING EXTENT OF ATMOSPHERIC POLLUTION[1]

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INTRODUCTION

The purpose of this paper are (1) to present a broad picture of the recognized methods of measuring the various forms of atmospheric pollution; (2) to evaluate the significance of such measurements; and (3) to suggest suitable methods for obtaining comparative information on the concentration of contaminants in city air.

ATMOSPHERIC CONTAMINANTS

The atmosphere (the gaseous envelope surrounding the earth) consists of a mixture of gases. These gases and their usual proportions are:[4]

Gas	Percent by volume in dry air
Nitrogen	78.09
Oxygen	20.95
Argon	.93
Carbon dioxide	.03
Neon	.0018
Helium	.00053
Krypton	.0001

The volume of water vapor in the atmosphere ranges from almost zero (in very cold weather) to about 5 percent and averages about 1.2 percent.

1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7210." Presented at the 35th Annual Convention of the Smoke Prevention Association of America, Inc., June 3-6, 1941, at Atlanta, Ga.

2/ Chemist, Gas and Dust Section, Health Division, Bureau of Mines, Central Experiment Station, Pittsburgh, Pa.

3/ Chief chemist, Health Division, Bureau of Mines, Pittsburgh, Pa.

4/ Humphreys, W. J., Physics of the Air: McGraw-Hill Book Co., Inc., New York, 3d. ed., 1940, 676 pp.

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Strictly speaking, any other substance in the atmosphere or an excess of any of the substances mentioned (with the possible exception of water) is a contaminant. Needless to say, there are many contaminants in the atmosphere.

In accordance with their physical state, contaminants may be classified as gaseous or particulate, and the latter may be classified as solid or liquid matter. Particulate matter, especially when dispersed in some medium such as air or some other gas, sometimes is referred to as dispersoid, and the complete system of gas and dispersoid is referred to as aerosol.

All substances on the earth are potential sources of atmospheric contaminants. Combustible materials (particularly fuel for heating and power), sea water, earth or soil, metals, and animals (including man) are some of the important sources of contaminants.

Ordinarily gases are produced by chemical processes, whereas dispersoids are produced by both chemical and physical processes. There are two general dispersoid-producing processes: (1) Condensation, in which molecules join to form larger units or particles, and (2) disintegration, in which large units are reduced to the particulate range (which for the purpose of this article may be considered to be from 100 microns, or 1/254 inch, down to molecular size) by such processes as crushing, grinding, abrading, and atomizing.

"Condensoid" is a convenient term for dispersoids formed by condensation, and "disintegrasoid" for those formed by disintegration. Solid condensoids are sometimes called "fume," solid disintegrasoids "dust," liquid condensoids "fog," and liquid disintegrasoids "mist."5/

Classification of Atmospheric Contaminants

Atmospheric contaminants, as referred to in this paper, are classified as follows:

1. Gaseous contaminants.
2. Particulate contaminants or dispersoids:
   - Solid dispersoids:
     - Condensoid, commonly called "fume."
     - Disintegrasoid, commonly called "dust."
   - Liquid dispersoids:
     - Condensoid, commonly called "fog."
     - Disintegrasoid, commonly called "mist."

5/ This nomenclature is used on the approval labels of dispersoid respirators approved by the Federal Bureau of Mines.

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The material ordinarily referred to as "smoke" is a mixture of various types of contaminants.

Contaminants are distributed in the atmosphere by air currents, gravity, and molecular bombardment (Brownian motion).

Gaseous contaminants are removed from the atmosphere by solution in raindrops, reaction with other substances, and physiological processes (such as removal of carbon dioxide from air by vegetation).

Dispersoids settle out of the air at different rates, depending on the size and density of the particles and air movement. Condensation of moisture on the particles and aggregation of colliding particles promote settlement.

The atmosphere is thus an unstable system. A great variety of contaminants is continuously disseminated into the atmosphere at irregular rates, various forces distribute these contaminants heterogeneously, and they leave the atmosphere at irregular rates.

Aerosols (air containing particulate matter) are much more complex and unstable systems than are gas-contaminated atmospheres. The composition of the units of particulate matter or dispersoids may be very complex, whereas that of the units (molecules) of a gas is uniform. The size properties of the units of dispersoids ordinarily are quite variable, whereas those of molecules are constant.

Table 1 contains information[6] on the size properties of dispersoids collected from the air of New York City by the Owens jet dust counter[7] and measured by a microprojection technique.[8]

6/ Yant, W. P., Levy, E., Sayers, R. R., Brown, C. E., Traubert, C. E., Frevert, H. W., and Marshall, K. L., Carbon Monoxide and Particulate Matter in Air of Holland Tunnel and Metropolitan New York: Bureau of Mines Rept. of Investigations 3585, 1941, table 22, p. 62.

7/ Owens, J. S., Jet Dust-Counting Apparatus: Jour. Ind. Hyg., vol. 4, 1923, pp. 522-534.

8/ Brown, C. E., and Yant, W. P., The Microprojector for Determining Particle-size Distribution and Number Concentration of Atmospheric Dust: Bureau of Mines Rept. of Investigations 3289, 1935, 8 pp. More modern equipment is described in the following article: Brown, C. E., Baum, L. A. H., Yant, W. P., and Schrenk, H. H., Microprojection Method for Counting Impinger Dust Samples: Bureau of Mines Rept. of Investigations 3373, 1938, 9 pp.

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TABLE 1. - Size properties of particulate matter in air of New York City

Item	Result
Sampler	Owens jet dust counter
Measuring technique	Microprojection
Number of samples	36
Average number of particles per sample measured	236
Percent of particles in indicated size range-limit of visibility to 0.5 micron	63.2
0.5 to 1.0 micron	29.9
1 to 2 microns	6.1
Above 2 microns	0.8
Geometric mean, micron	.41
Standard geometric deviation	1.85

Many data have been published on contaminated atmospheres, especially on dispersoid-contaminated ones.9/-15/

HARMFUL AND OTHERWISE OBJECTIONABLE ASPECTS OF ATMOSPHERIC CONTAMINANTS

Some purely scientific investigations have been made on atmospheric contaminants, but most investigations of such contaminants are stimulated by their harmful and otherwise objectionable aspects.

9/ Gibbs, W. E., Clouds and Smokes, The Properties of Disperse Systems in Gases and Their Practical Applications: P. Blakiston's Son & Co., Philadelphia, 1924, 240 pp.

10/ Faraday Society, General Discussion Disperse Systems in Gases; Dust, Smoke, and Fog: Trans. Faraday Soc., vol. 52, 1936, pp. 1041-1300. Reprinted by Gurney & Jackson, London and Edinburgh.

11/ Whytlaw-Gray, R., and Patterson, H. S., Smoke: Edward Arnold & Co., London, 1932, 192 pp.

12/ Drinker, P., and Hatch, T., Industrial Dust: McGraw-Hill Book Co., Inc., New York, 1936, 316 pp.

13/ Shaw, N., and Owens, J. S., The Smoke Problem of Great Cities: Constab & Co., Ltd., London, 1925, 301 pp.

14/ Blacktin, S. C., Dust: Sherwood Press, Cleveland, 1934, 296 pp.

15/ Ives, J. E., Britten, R. H., Armstrong, D. W., Gill, W. A., and Goldman, F. H., Atmospheric Pollution of American Cities for the Years 1931 to 1933: Pub. Health Bull. 224, 1936, 75 pp.

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Atmospheric contaminants do or may affect the health, activities, and attitude (or morale) of man (and possibly of other members of the animal kingdom); the health and growth of vegetation; and the wear, composition, and appearance of inanimate objects.16/-23/ Thus virtually all earthly things are or may be affected by such contaminants.

Man's health may be affected by direct inhalation of the contaminants or by failure to receive the beneficial effects of the sun rays, which are blocked by atmospheric contaminants. Some contaminants that exert definite effects on health when inhaled (in sufficient quantity) are inorganic particulate matter, such as free silica or quartz, lead, manganese, mercury, chromium (hexavalent), arsenic, and antimony; organic particulate matter, such as pollen, seeds, plant and animal debris, and bacteria; and gases, such as sulfur dioxide, oxides of nitrogen, and ozone. Ordinarily, few of these substances are present in the atmosphere in high enough concentration to exert significant effects. Low concentrations of these constituents and various concentrations of other constituents may affect the resistance of persons to certain diseases, particularly of the respiratory system.

Much human activity is devoted to removing deposited atmospheric contamination from the body, clothing, and habitations and to preventing the wear and corrosion of materials by such contamination. The colored dispersoids, mainly carbonaceous in nature, are responsible for much soiling; the hard, gritty dispersoids for wear; and the acid and alkaline gases for corrosion.

16/ Public Health Service, City Smoke and Its Effects: Pub. Health Repts., vol. 51, 1936, pp. 15-18.

17/ American Medical Association, Atmospheric Contamination: Jour., vol. 110, 1938, p. 1839.

18/ Schnurer, L., Further Studies on the Relation of Pneumoconiosis to Respiratory Diseases in the Pittsburgh District: Jour. Ind. Hyg. Toxicol., vol. 20, 1938, pp. 14-23.

19/ Schnurer, L., Effects of Inhalation of Smoke from Common Fuels: Am. Jour. Pub. Health, vol. 27, 1937, pp. 1010-1022.

20/ Sayers, R. R., Harmful Industrial Dusts: Pub. Health Repts., vol. 53, 1938, pp. 217-228.

21/ Wodehouse, R. P., Pollen Grains: Their Structure, Identification, and Significance in Science and Medicine: McGraw-Hill Book Co., Inc., New York, 1935, 568 pp.

22/ Wells, W. F., Wells, M. W., and Mudd, S., Infection of Air: Am. Jour. Pub. Health, vol. 29, 1939, pp. 863-880.

23/ Setterstrom, C., Effects of Sulfur Dioxide on Plants and Animals: Ind. Eng. Chem., vol. 32, 1940, pp. 473-479.

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Visible dispersoids in the air affect the morale of people, as is evidenced by the smoke-abatement movement.

Some plants are harmed by even very low concentrations of gases such as sulfur dioxide.

DETERMINATIONS ON ATMOSPHERIC CONTAMINANTS

Determinations of atmospheric contaminants are made by workers in such fields as smoke prevention, industrial hygiene, ventilation (including heating and air conditioning), meteorology, dust control, dust explosions, combustion, gas engineering, compressed-air engineering, public health, and safety.24/-32/ Some of these workers are interested in total contamination, whereas others are interested only in particular constituents.

General determinations of concentration of both gaseous and particulate contaminants and composition and size properties of only the particulate

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24/ Smoke Prevention Association of America, Inc., Manual of Ordinances and Requirements: 1940, 160 pp.

25/ Jacobs, M. B., The Analytical Chemistry of Industrial Poisons, Hazards and Solvents: Interscience Publishers, Inc., New York, 1941, 650 pp.

26/ Zhitkova, A. S., Kaplan, S. D., and Ficklen, J. B., Some Methods for the Detection and Estimation of Poisonous Gases and Vapors in the Air. A Practical Manual for the Industrial Hygienist: Service to Industry, Box 133, West Hartford, Conn., 198 pp.

27/ International Labor Office, Industrial Environment and Health; Practical Methods of Investigation: International Labor Office, Geneva, 1936, 336 pp.

28/ Air Hygiene Foundation of America, Inc., Routine Sampling for Control of Atmospheric Impurities: Preventive Eng. Series, Bull. 2, Pt. 8, 1939, 19 pp.

29/ American Public Health Association, Industrial Hygiene Section, Ventilation and Atmospheric Pollution Reports: Am. Pub. Health Assoc. Yearbooks.

30/ British Advisory Committee on Atmospheric Pollution, Annual Reports: 1st to 6th repts. published as supplements to the Lancet, February 26, 1916; October 27, 1917; March 23, 1918; June 14, 1919; November 15, 1919; and November 20, 1920. 7th to 19th repts. published by His Majesty's Stationery Office from 1922 to 1934. (This information from reference 15.)

31/ New York Meteorological Observatory (under direction of New York City and U. S. Dept. of Commerce, Weather Bureau), Reports since 1931.

32/ DallaValle, J. M., and Hollaender, A., The Effectiveness of Certain Type of Commercial Air Filters Against Bacteria: Pub. Health Repts. vol. 54, 1939, pp. 695-699.

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contaminants are made by workers in many of these fields, but use of the same methods in two or more fields or even by all workers in the same field is the exception rather than the rule. This is due mainly to the complexity and instability of contaminated atmospheres, variations in the nature of atmospheres in the different fields and in the type of information desired, and the difficulty of making determinations on the small quantities of contaminants ordinarily found. It is questionable whether suitable standard procedures can be devised for each of these determinations, but much can be done to improve present chaotic conditions.

Determination of atmospheric contaminants comprises at least three important steps: (1) Consideration of the purpose of the determination and of the nature of the information to be obtained, (2) sampling, and (3) determination. The first step needs little or no discussion.

Sampling

Sampling does not necessarily involve removal of the contaminant from the air, but it should always involve careful selection of the proper place, time, and interval for making the determination or removing the contaminant. The importance of sampling in making determinations on such a complex and unstable system as the atmosphere can scarcely be overemphasized.

The sampling of gases is ordinarily a much simpler procedure than the sampling of dispersoids, as gases diffuse readily and do not settle significantly under the influence of gravity, and as their units or molecules are uniform in composition and size. Samples of most gases are commonly obtained by collecting a small volume of the gas-contaminated atmosphere in a suitable container.[33/], [34/] Frequently, small, evacuated, glass containers are used for this purpose.

Conversely, the sampling of dispersoids usually is much more difficult because the particles do not diffuse readily throughout the atmosphere, the composition and size of the individual units ordinarily vary widely, the particles settle under the influence of gravity, at rates depending on their size and density, and the units tend to aggregate upon collision, thus changing in size and settling rate.

The efficient removal of particulate matter from the air is not a simple procedure. There are many dispersoid-sampling devices and even more proposals for such devices. The collecting efficiency and practicability of the devices vary widely. These samplers have been well-reviewed in the

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33/ Purrell, G. A., and Seibert, F. M., Sampling and Examination of Mine Gases and Natural Gas: Bureau of Mines Bull. 197 (revised by G. W. Jones), 1926, 108 pp.

34/ American Gas Association, Gas Chemists' Handbook: New York, latest edition.

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technical literature.35/-57/ Only the operating principles of these devices and the samplers of particular interest in the field of smoke prevention will be discussed briefly here.

35/ Palmer, G. T., Coleman, L. V., and Ward, H. C., A Study of Methods for Determining Air Dustiness: Am. Jour. Pub. Health, vol. 6, 1916, pp. 1049-1075.

36/ Hill, E. V., Quantitative Determination of Air Dust: Heat. Vent. Mag., vol. 14, June 1917, pp. 23-33.

37/ Knowles, E. R., Dust Determination in Air and Gases: Jour. Am. Soc. Heat. Vent. Eng., vol. 25, 1919, pp. 67-98.

38/ Smyth, H. G., A Critical Review of Methods for the Study of Dust Content of Air: Jour. Ind. Hyg., vol. 1, 1919-1920, pp. 140-149.

39/ Bill, J. P., The Electrostatic Method of Dust Collection as Applied to the Sanitary Analysis of Air: Jour. Ind. Hyg., vol. 1, 1919-1920, pp. 323-342.

40/ Warren, P. H., and Read, T. A., Methods and Apparatus for the Determination of Dust Suspended in Air: Proc. Australasian Inst. Min. Met., N. S. No. 47, 1922, pp. 297-342.

41/ Drinker, P., Thomson, R. M., and Fitchet, S. M., Atmospheric Particulate Matter: 1. Dust, with a New Apparatus for its Determination: Jour. Ind. Hyg., vol. 5, pp. 19-35 and 62-78.

42/ Gibbs, W. E., Work cited in footnote 9, page 4.

43/ Greenburg, L., Studies on the Industrial Dust Problem II. A Review of the Methods Used for Sampling Aerial Dust: Pub. Health Repts., vol. 40, 1925, pp. 765-786.

44/ Katz, S. H., Smith, G. W., Myers, W. M., Trostel, L. J., Ingels, M., and Greenburg, L., Comparative Tests of Instruments for Determining Atmospheric Dusts: Pub. Health Bull. 144, 1925, 69 pp.

45/ Shaw, W., and Owens, J. S., Work cited in footnote 13, p. 4.

46/ Heymann, B., Die Verfahren zur quantitativen Bestimmung des Staubes in der Atemluft: Zentralbl. f. d. gesamte Hyg., vol. 24, 1932, pp. 1-38.

47/ Shnidman, L., Review of Methods for the Determination of Dust in Gas: Presented at A. G. A. Joint Committee Conference of the Production and Chemical Committees, New York, May 1933.

48/ Green, H. L., Recent Developments in Methods of Sampling Dusts: Bull. Inst. Min. and Met. (London), No. 362, November 1934, 21 pp.

49/ Bloomfield, J. J., and DallaValle, J. M., The Determination and Control of Industrial Dust: Pub. Health Bull. 217, 1935, 167 pp.

50/ Drinker, P., and Hatch, T., Work cited in footnote 12, p. 4.

51/ Ives, J. E., and others, Work cited in footnote 15, p. 4.

52/ Brown C. E., Equipment and Methods for Determining Air Dustiness in Mines: Min. Cong. Jour., vol. 22, 1936, pp. 28-33 and 49.

53/ Schrenk, H. H., Rapid Methods for the Estimation of Air Dustiness: Amer Jour. Pub. Health, vol. 30, 1940, pp. 1183-1190.

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54/ Faber, O. M., Gravimetric, Tyndallmetric, and Konimetric Measurement of Dust: Staub, vol. 7, 1937, pp. 372-408.
55/ Faber, O. M., Method for Dust Determinations in Small Samples: Staub, vol. 8, 1938, pp. 4-46.
56/ Lambrechts, J. deV., A Critical Review of Dust-Sampling Methods Employed in Witwatersrand Gold Mines: Jour. Chem., Met., and Min. Soc. S. Africa, vol. 141, 1940, pp. 209-240.
57/ Griffiths, J. H., and Jones, T. D., The Determination of Dust-Concentrations in Mine Atmospheres: Trans. Inst. Min. Eng. (London), vol. 99, 1940, pp. 150-162. Addendum and discussion to p. 180.

Settling, filtering, washing, impinging, electric precipitation, and thermal precipitation are the operating principles of most of the devices proposed for collecting particulate matter from the air.

As the settling rate of dispersoids from aerosols varies with size and density of the particles, settling is not a suitable procedure for collecting samples of the particulate matter in unconfined atmospheres. It is satisfactory (and much used) for collecting samples of the settled or deposited material from such atmospheres. It is also fairly satisfactory for collecting samples of the particulate matter in atmospheres confined in various sedimentation cells and other containers.58/ The slow settling rate of the very fine particles and the possibility of some of the particles depositing upon the ceiling and walls of the cell are disadvantages of this procedure.

Filtration of the aerosol through fibrous or granular filters is much used in the collection of samples of dispersoids from aerosols. The collecting efficiency of filters varies widely, therefore care must be used in selecting a suitable filter for a particular purpose. The collecting efficiency and resistance to air flow of filters tend to increase with the quantity of solid dispersoid collected. This increase in resistance to air flow and the difficulty of removing the collected material from the filter are objections to samplers using this principle.

Washing or bubbling the aerosol through a liquid is a notoriously inefficient method of removing particulate matter from aerosols unless the bubbles are small enough to insure contact between the bubble contents and the liquid.

Impinging the aerosol against plain or adhesive-coated surfaces is the operating principle of many samplers whose collecting efficiencies vary

58/ Green, H. L., Some Accurate Methods of Determining the Number and Size-frequency of Particles in Dusts: Jour. Ind. Hyg., vol. 16, 1934, pp. 29-39.

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widely.59/-66/ A few of these samplers have a high but somewhat selective (for particles in different size ranges) collecting efficiency. There is evidence of shattering of particles or aggregates in samples collected by some of these samplers.67/-70/

59/ Miners' Phthisis Prevention Committee, Final Report: Government Printing and Stationery Office, Pretoria. Johannesburg, 1919, 110 pp.

60/ Mavrogordato, A., The Value of the Konimeter - Being an Investigation into the Methods and Results of Dust-sampling as at Present Practiced in the Mines on the Witwatersrand: South Africa Inst. Med. Res. Pub. 17, Johannesburg, 1923.

61/ Norman, G. H. C., Methods of Sampling and Dust Determination in the Mines of Ontario: Min. Technol., Am. Inst. Min. and Met. Eng., Tech. Pub. 857, 1937, 20 pp.

62/ Lambrechts, J. deV., Work cited in footnote 56, p. 9.

63/ Littlefield, J. B., Brown, C. E., and Schrenk, H. H., Technique for Routine Use of the Konimeter: Bureau of Mines Inf. Circ. 6993, 1938, 6 pp.

64/ Owens, J. S., Work cited in footnote 7, p. 3.

65/ Shaw, W., and Owens, J. S., Work cited in footnote 13, p. 4.

66/ Hatch, T., and Thompson, E. W., A Rapid Method of Dust Sampling and Approximate Quantitation for Routine Plant Operation: Jour. Ind. Hyg., vol. 16, 1934, pp. 92-99.

67/ Ficklen, J. B., and Golden, L. L., The Behavior of Certain Dusts Under Mechanical Impingement: Science, vol. 85, 1937, pp. 587-588.

68/ Anderson, E. L., The Effect of Certain Impingement Dust-sampling Instruments on the Dust Particles: Jour. Ind. Hyg. Toxicol., vol. 21, 1939, pp. 39-47.

69/ Watson, H. H., A Note on the Shattering of Dust Particles in the Impinger: Jour. Ind. Hyg. Toxicol., vol. 21, 1939, pp. 121-123.

70/ Beadle, D. G., The Shattering of Dust Particles by the Impinger: Jour. Ind. Hyg. Toxicol., vol. 21, 1939, pp. 109-120.

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A combination of washing and impinging is employed in the impinger, the main dispersoid sampler used by industrial hygienists in this country.71/-77/ The collecting efficiency of this device is high for particles down to a little less than 1 micron in diameter but tends to decrease with decrease in size below this.

Electric precipitation by high-voltage direct or alternating current is one of the most efficient and best methods of collecting all kinds of particulate matter from the air.78/-91/ It is about the only suitable procedure for

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71/ Greenburg, L., The Greenburg-Smith Impinger Sampling Apparatus for Dusts, Fumes, Smoke, and Gases: Am. Jour. Pub. Health, vol. 22, 1932, pp. 1077-1082.

72/ Greenburg, L., and Bloomfield, J. J., The Impinger Dust-sampling Apparatus as Used by the U. S. Public Health Service: Pub. Health Repts., vol. 47, 1932, pp. 654-675.

73/ Hatch, T., Warren, H., and Drinker, P., Modified Form of the Greenburg-Smith Impinger for Field Use, with a Study of Its Operating Characteristics: Jour. Ind. Hyg., vol. 14, 1932, pp. 301-311.

74/ Hatch, T., and Pool, C. L., Quantitation of Impinger Dust Samples by Dark-Field Microscopy: Jour. Ind. Hyg., vol. 16, 1934, pp. 177-191.

75/ Schrenk, H. H., and Feicht, F. L., Bureau of Mines Midget Impinger: Bureau of Mines Inf. Circ. 7076, 1939, 7 pp.

76/ Brown, C. E., Baum, L. A. H., Yant, W. P., and Schrenk, H. H., Microprojection Method for Counting Impinger Dust Samples: Bureau of Mines Rept. of Investigations 3373, 1938, 9 pp.

77/ Brown, C. E., and Schrenk, H. H., A Technique for Use of the Impinger Method: Bureau of Mines Inf. Circ. 7026, 1938, 20 pp.

78/ Cottrell, F. G., The Electrical Precipitation of Suspended Particles: Jour. Ind. Eng. Chem., vol. 3, 1911, pp. 542-550.

79/ Tolman, R. C., Reyerson, L. H., Brooks, A. P., and Smyth, H. D., An Electrical Precipitator for Analyzing Smokes: Jour. Am. Chem. Soc., vol. 41, 1919, pp. 587-589.

80/ Lamb, A. B., Wendt, G. L., and Wilson, R. E., Portable Electrical Filter for Smokes and Bacteria: Trans. Am. Electrochem. Soc., vol. 35, 1919, pp. 357-365.

81/ Hill, J. P., Work cited in footnote 39, p. 8.

82/ Drinker, P., Thomson, R. M., and Fitchet, S. M., Atmospheric Particulate Matter: II. The Use of Electric Precipitation for Quantitative Determination and Microscopy: Jour. Ind. Hyg., vol. 5, 1923, pp. 162-185.

83/ Weber, H. C., Quantitative Analysis of Mists and Fogs, Especially Acid Mists: Jour. Ind. Eng. Chem., vol. 16, 1924, pp. 1239-1242.

84/ Drinker, P., and Thomson, R.M., Determination of Suspensoids by Alternating-current Precipitators: Jour. Ind. Hyg., vol. 7, 1925, pp. 261-272.

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85/ Drinker, P., Alternating-current Precipitators for Sanitary Air Analysis. I. An Inexpensive Precipitator Unit: Jour. Ind. Hyg., vol. 14, 1932, pp. 364-367.
86/ Hazard, W. G., and Ishikawa, T., Alternating-current Precipitators for Sanitary Air Analysis. II. Acid Formation in Electric Precipitators: Jour. Ind. Hyg., vol. 14, 1932, pp. 367-370.
87/ Barnes, E. C., Dust Determinations: Am. Jour. Pub. Health, vol. 26, 1936, pp. 274-278.
88/ Barnes, E. C., and Penney, G. W., An Electrostatic Dust-count Sampler: Jour. Ind. Hyg. Toxicol., vol. 18, 1936, pp. 167-172.
89/ Barnes, E. C., and Penney, G. W., An Electrostatic Dust-weight Sampler: Jour. Ind. Hyg. Toxicol., vol. 20, 1938, pp. 259-265.
90/ Schmidt, W. A., and Anderson, E., Electrical Precipitation: Elec. Eng., vol. 57, 1938, pp. 332-338.
91/ Schrenk, H. H., Testing and Design of Respiratory Protective Devices: Bureau of Mines Inf. Circ. 7086, 1939, 11 pp.

efficiently collecting significant amounts of very fine dispersoids, such as lead and other metallic oxide fumes, from aerosols. The possibility of causing explosions in potentially explosive atmospheres, of modifying the composition of easily oxidized dispersoids,92/ and of converting some gases or vapors into particulate matter are disadvantages of this method.

Thermal precipitation (repelling particles from a hot surface onto a cold or cooler one) has been adopted recently for a sampler that is apparently gaining some acceptance as a standard or reference scientific device in Great Britain and some of the dominions (especially South Africa).93/-95/ The collecting efficiency of this device is apparently high, but the capacity is quite low (sampling rate, about 7 ml. or 0.00025 cubic foot per minute).

92/ Glockler, G., and Lind, S. C., The Electrochemistry of Gases and Other Dielectrics: John Wiley & Sons, Inc., New York, 1939, 469 pp.
93/ Green, H. L., and Watson, H. H., Physical Methods for the Estimation of the Dust Hazard in Industry, with special Reference to the Occupation of Stonemason: Privy Council, Medical Research Council, Special Report Series 199, H. M. Stationery Office, London, 1935, 56 pp.
94/ Watson, H. H., A System for Obtaining from Mine-air Dust Samples for Physical, Chemical, and Petrological Examinations: Jour. Chem., Met. and Min. Soc. South Africa, vol. 37, 1936, pp. 166-138; also Bull. Inst. Min. Met. Eng. (London), November 1936.
95/ Patterson, H. S., Sampling of Mine Dusts with the Thermal Precipitator: Inst. Min. Met. Bull. 417, June 1939, 7 pp.

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The sampling rates of the different samplers, that is, the amount of material that can be collected per unit of time, vary widely. Filters and electric precipitators ordinarily have a higher sampling rate than do the other types of samplers; thus they are frequently much used for collecting the relatively large quantities of materials needed in determinations such as weight concentration and composition from chemical analyses.

The general places for sampling atmospheric contaminants are (1) at or near the point of generation of the contaminant, (2) at or near its point of dissemination into the general atmosphere, and (3) in the general atmosphere. Sampling at or near the point of generation or dissemination of the contaminant may involve sampling in an enclosed passageway, such as a stack, duct, or pipe line. Special precautions as to location of the intake of the sampler and regulation of the flow into the intake to correspond with the flow in the passageway must be observed in collecting samples in such places.

Determinations

Concentration of gaseous contaminants and concentration, composition, and size properties of particulate contaminants are the main determinations made on contaminated atmospheres.

Concentration

The concentration of gaseous contaminants ordinarily is determined by well-established chemical or physical procedures. The standardization of these determinations has progressed much farther than that of determinations for dispersoids.

Estimation of concentration is the main determination made on dispersoids. These estimations may be classified into (1) direct estimations, in which the concentration of the dispersoid is estimated directly by weighing or counting the number of microscopically visible units in samples collected from measured volumes of aerosol, and (2) indirect estimations, in which some property related to concentration is measured.

Direct methods

Weight concentration. - The closest approximation to the concentration of all the (solid or nonvolatile matter) dispersoid in an aerosol probably can be made by carefully weighing a sample efficiently collected from a measured volume of the aerosol. This procedure is used by the Bureau of Mines in its approval work on dispersoid respirators and in various experimental work.96/

96/ Schrenk, H. H., Work cited in footnote 91, p. 12.

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Figure 1 is a sketch of the sampler employed. The dispersoid in the aerosol, which is drawn through the sampler at a measured rate, is precipitated in the small glass tube inside the wire-screen collecting electrode and around the central or precipitating electrode. The tube and central electrode are designed for convenience in weighing on an ordinary quantitative chemical balance. A similar tube and central electrode, whose total weight does not differ from the first by more than 0.5 gm. or 500 mg., is used as a tare in all weighings. The precision of this method is about ± 0.1 mg., at least for nonhygroscopic dusts like quartz. The Bureau of Mines has also determined the concentration of dispersoids in city air by a weighing procedure in which the dispersoid was collected from the air by filtration through a pad of three quantitative (Whatman No. 42) filter papers.97/ Similar unpublished studies have been made recently, using an electric precipitator for collecting the dispersoids from the air. Weighing methods also have been much used by others.

Some of the main disadvantages of weighing follow.

1. Necessity for sampling large volumes of air. The concentration of dispersoids in ordinary air is of the order of a fraction of a milligram per cubic meter (1 mg./m.^{3} = 0.00044 grain per cubic foot), thus several cubic meters (1 cubic meter = 35.314 cubic feet) must be sampled to obtain a readily weighable sample.

2. Emphasis on the larger particles. Mass varies with the cube of the diameter; thus, a 10-micron particle weighs as much as 1,000 1-micron particles. Large particles settle out of the air so rapidly that they are rarely found in ordinary city air. The high relative weight of the larger particles emphasizes the importance of preventing contamination of the samples by these particles. Little difficulty in preventing such contamination has been experienced in this laboratory, as evidenced by the agreement of the results of duplicate weight determinations under many conditions.

The concentration of certain dispersoid contaminants will be discussed later in the section on determination of composition.

Number concentration. - The number concentration of dispersoids in various size ranges is determined by numerous microscopic counting procedures. Obviously, only the particles rendered visible by the optical system employed are counted by these procedures. There is very little information on the limit of visibility (size of smallest units made visible) of the various optical systems used. Virtually all of the microscopically visible particles present in the ordinary atmosphere are so extremely fine that it seems

97/ Yant, W. P., and others, Work cited in footnote 6, p. 3.

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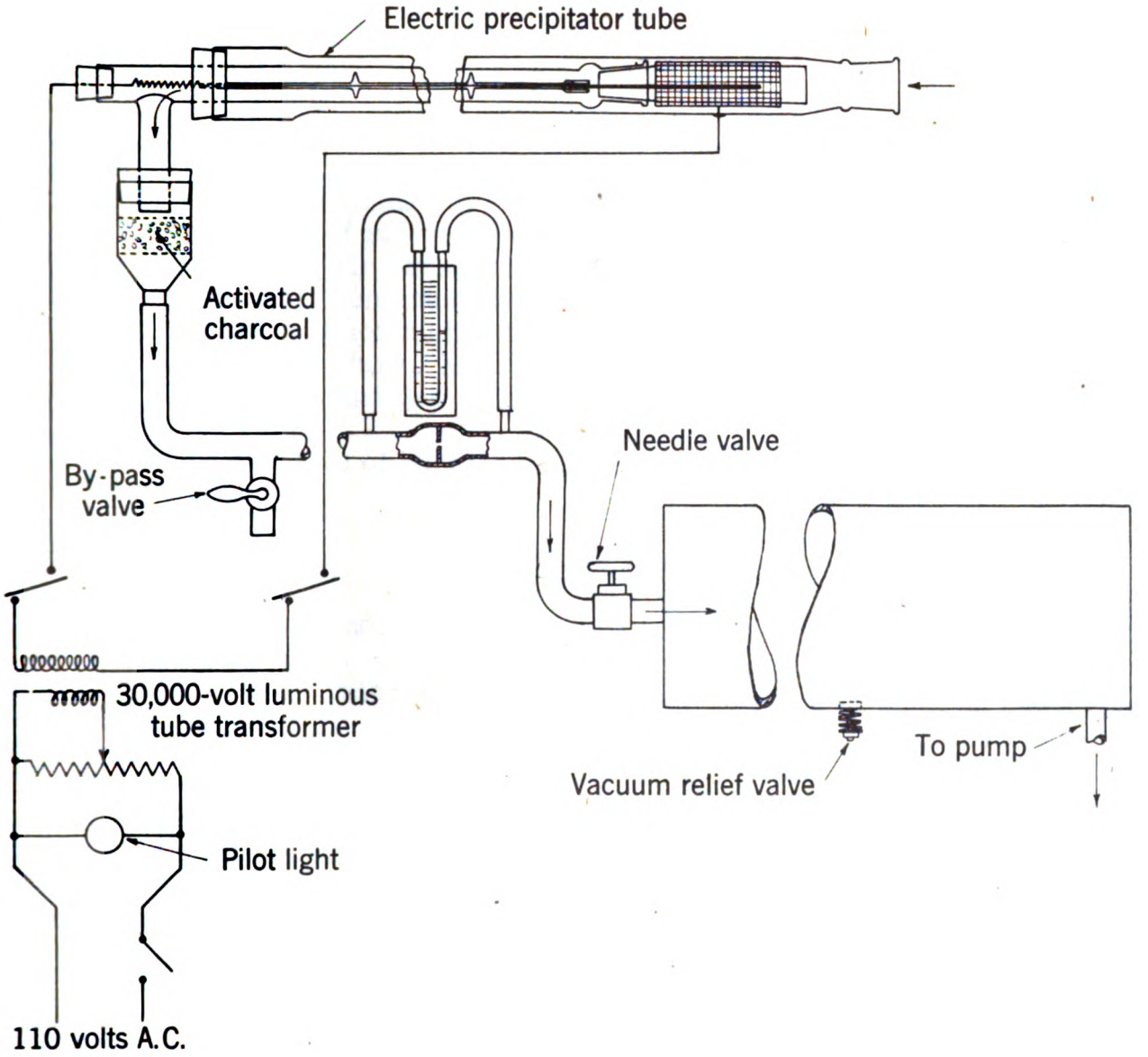

Figure 1.—Dust-sampling apparatus.

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reasonable to presume that many are below the limit of visibility of the microscope. The new electron microscope should provide data on this subject.

Information on the number concentration of the microscopically visible particles in city air has been obtained from samples collected from the air by the Owens jet dust counter (an impingement sampler) and counted under a light-field, oil-immersion microscopic system, the limit of visibility of which is probably of the order of 0.2 micron.98/-101/

Information on number concentration of droplet nuclei in air has been obtained by a device designed by Aitken.102/, 103/ In this method, moisture from a known volume of saturated air is caused to condense on the nuclei by suddenly reducing the air pressure. The drops settle on a measured area of a glass slide and are then counted under a simple microscope. The results ordinarily are many times higher than corresponding results with the Owens jet dust-counting procedure. Moisture apparently condenses not only on particles but also on ions and gas molecules.

The concentration of bacteria and pollen in the air is commonly determined by number.

Indirect Methods

There are many indirect methods for estimating the concentration of dispersoids in aerosols. Color or shade comparison, light reflection, and light transmission or absorption are the main principles of most of these procedures. The majority of the methods used in the field of smoke prevention for estimating the concentration of dispersoids in aerosols are indirect. The Ringelmann chart, umbrascope, and Owens automatic air-filter procedures employ color or shade comparison. The photoelectric smoke alarms and recorders for use in or on stacks use the principle of light transmission or absorption.

98/ Shaw, N., and Owens, J. S., Work cited in footnote 13, p. 4.
99/ Kimball, H. H., and Hand, I. F., Investigation of the Dust Content of the Atmosphere: Monthly Weather Review, vol. 52, 1924, pp. 133-139; vol. 53, 1925, pp. 243-246; and vol. 59, 1931, pp. 349-352.
100/ Ives, J. E., and others, Work cited in footnote 15, p. 4.
101/ Yant, W. P., and others, Work cited in footnote 6, p. 3.
102/ Aitken, J., On a Simple Pocket Dust Counter: Proc. Royal Sec. Edinburgh, vol. 18, 1890-91, pp. 39-52. See also Collected Scientific Papers of John Aitken, Cambridge University Press, 1923, pp. 236-246 (from Ives, J. E., and others, footnote 15, p. 4.)
103/ Wait, G. R., The Aitken Pocket Nuclei-Counter: Gerlands Beitrage zur Geophysik, vol. 37, 1932, pp. 429-439 (from Ives, J. E., and others, footnote 15, p. 4.)

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The results obtained by these indirect methods are approximate at best, especially so in making estimates on complex dispersoids such as those present in city air. Figure 2, which illustrates this fact, contains photographs of samples of dispersoids collected from the air of the Holland Vehicular Tunnel and of Metropolitan New York during two seasons of the year, spring and winter, by filtration of the aerosols through quantitative (Whatman No. 42) filter paper.[104] The weight of the collected material was determined carefully. These photographs show that the color or shade of the collected material did not vary with the weight of the material in either study, and that the color or shade of the material collected in the winter study was significantly darker, in all instances except one, than the corresponding weight of material collected at the same places during the spring study. Figure 3 contains similar information. This figure is a graphic presentation of the relationship between the results of the weight-concentration determinations (by the filter-paper procedure) and estimations of the concentration of the dispersoids in the air of Central Park during the same period by the Owens automatic air filter[105] in the New York Meteorological Observatory. The factor of 0.32 supplied with this filter for converting the shade numbers into estimations of the weight concentration, in milligrams per cubic meter, was employed in obtaining these data. These data also show that the Owens filter gives only a rough estimation of the total concentration of dispersoids in the air sampled, and that it tends to overestimate the weight concentrations (at least in the air of New York City) in cold weather and underestimate the concentrations during the warm seasons. Although neither this nor other devices employing the same principle closely estimate the concentration of the total dispersoid present in city air, they do give valuable data on the approximate concentration of the colored dispersoid that is responsible for much of the soiling and visible properties of dispersoids.

Composition

Satisfactory methods are available for the determination of virtually all important atmospheric contaminants except free silica or quartz, and indications are than an X-ray procedure may be suitable for this substance.[106] The main principles used in these methods are chemical (macro- and micro-),

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104/ Yant, W. P., and others, Work cited in footnote 6, p. 3.
105/ Ives, J. E., and others, Work cited in footnote 15, p. 4.
106/ Ballard, J. W., Oshry, H. I., and Schrenk, H. H., Quantitative Analysis by X-ray Diffraction. I. Determination of Quartz: Bureau of Mines Rept. of Investigations 3520, 1940, 10 pp.

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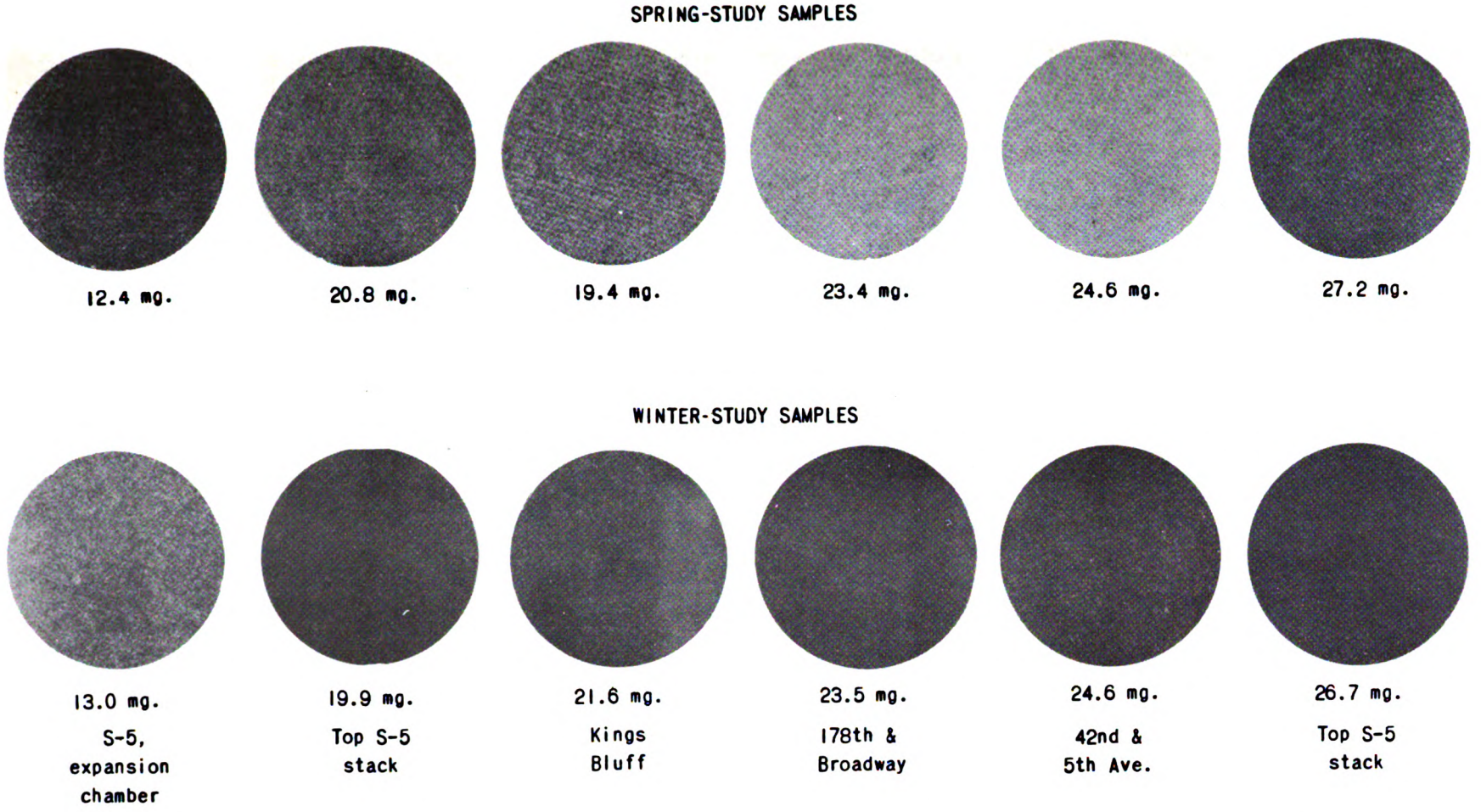

Figure 2.—Comparison of color or shade of particulate matter collected in the spring study with that collected in the winter study.

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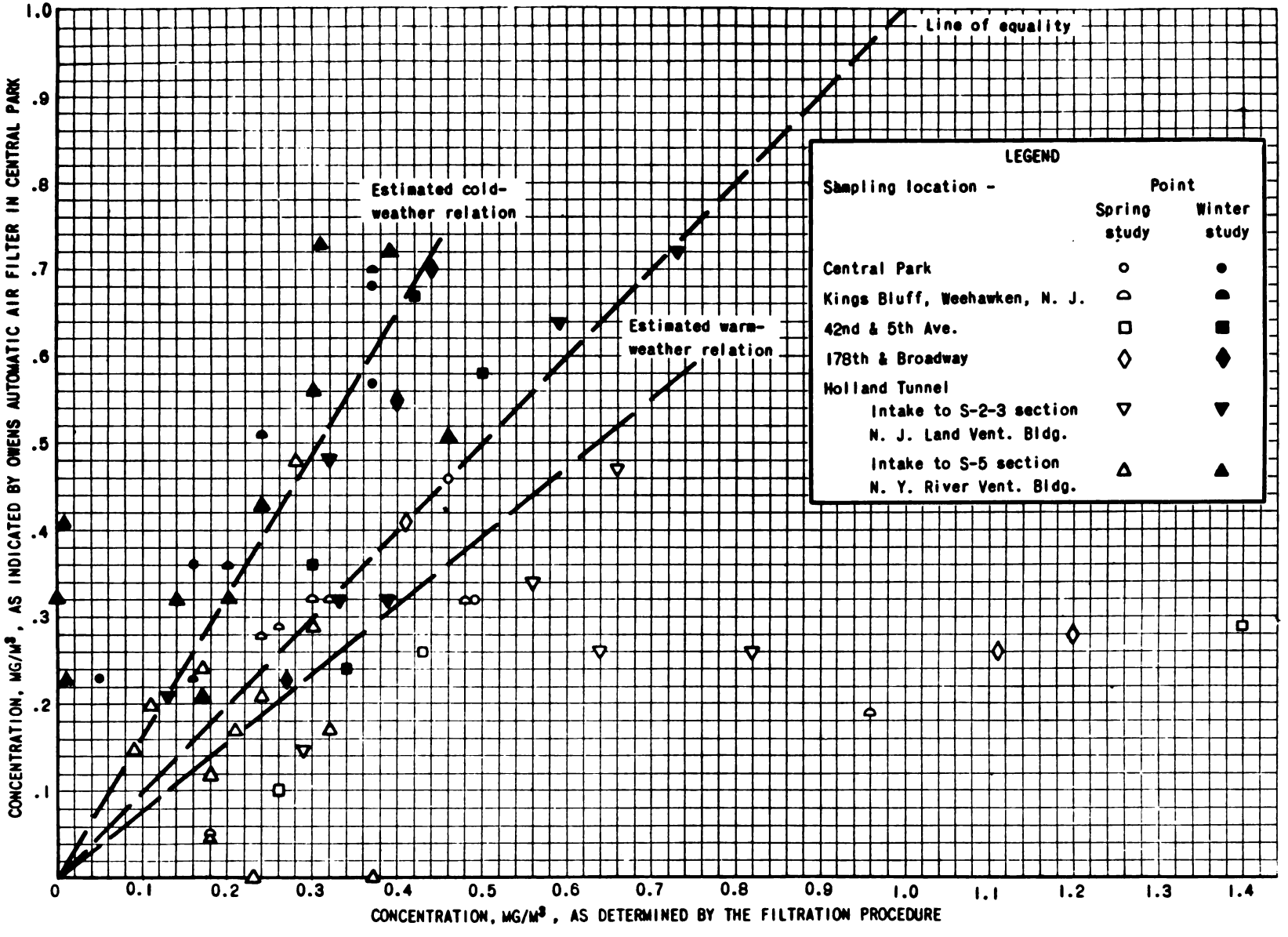

Figure 3.—Results of weight-concentration determinations of particulate matter in the air of Metropolitan New York versus estimations by the Owens automatic air filter in Central Park.

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electrochemical,[107] petrographic,[108] spectrographic,[109] and radiographic. The technical literature contains much information on these methods.

Size Properties

Particulate matter fine enough to remain in the air for even a short time is small enough to pass through the finest available sieves. Microscopic measurement is about the only direct method of obtaining data on the size properties of such extremely fine and complex material, and this procedure, of course, only gives information on the particles made visible by the optical system used. A convenient method is to collect samples from the air by the thermal precipitator or Owens jet dust counter; project the images of the particles under a light-field, oil-immersion, microscopic system onto a calibrated, translucent screen, and compare the size of the images with the rulings on the screen.[110] Several other procedures are available for such determinations.

There are many indirect methods of obtaining information on the size properties of particulate matter. They are mainly applicable to single substances rather than mixtures like those ordinarily present in the air of cities.

References are given to some of the important literature on size properties of particulate matter.[111]-[120]

107/ Kolthoff, I. M., and Lingane, J. J., Polarography, Polarographic Analysis Voltammetry, Amperometric Titrations: Interscience Publishers, Inc., New York, 1941, 500 pp.

108/ Foster, W. D., and Schrenk, H. H., Petrographic Identification of Atmospheric Dust Particles: Bureau of Mines Rept. of Investigations 3363, 1938, 10 pp.

109/ Duffendack, O. S., and Wolfe, R. A., Analysis of Caustic Liquors for Traces of Impurities: Ind. Eng. Chem., anal. ed., vol. 10, 1938, pp. 161-164.

110/ Yant, W. P., and others, Work cited in footnote 8, p. 3.

111/ Work, L. T., Methods of Particle-size Determination: Proc. Am. Soc. Test. Materials, vol. 28, Tech. Papers, pt. 2, 1928, pp. 771-812.

112/ Heywood, H., Measurement of the Fineness of Powdered Materials: Proc. Inst. Mech. Eng., vol. 140, 1938, pp. 257-308. (See bibliography).

113/ Chamot, E. M., and Mason, C. W., Handbook of Chemical Microscopy. Vol. 1, Principles and Use of Microscopes and Accessories, Physical Methods for the Study of Chemical Problems: John Wiley & Sons, Inc., New York, 1938, 2d ed., Ch. 13, 478 pp.

114/ Perrott, G. St. J., and Kinney, S. P., The Meaning and Microscopic Measurement of Average Particle Size: Jour. Am. Ceram. Soc., vol. 6, 1923, pp. 417-439.

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115/ Green, H., The Effect of Nonuniformity and Particle Shape on "Average Particle Size": Jour. Franklin Inst., vol. 204, 1927, pp. 713-729.
116/ Loveland, R. P., and Trivelli, A. P. H., Mathematical Methods of Frequency Analysis of Size of Particles: Jour. Franklin Inst., vol. 204, 1927, pp. 193-217 and 377-389.
117/ Drinker, P., The Size-frequency and Identification of Certain Phagocytosed Dusts: Jour. Ind. Hyg., vol. 7, 1925, pp. 305-316.
118/ Hatch, T., and Choate, S. P., Statistical Description of the Size Properties of Nonuniform Particulate Substances: Jour. Franklin Inst., vol. 207, 1929, pp. 369-387.
119/ Dunn, E. J., and Shaw, J., Factors in the Presentation and Comparison of Particle-size Data: Proc. Am. Soc. Test. Materials, vol. 33, Tech. Papers, pt. 2, 1933, pp. 692-703.
120/ Austin, J. B., Methods of Representing Distribution of Particle Size: Ind. Eng. Chem., anal. ed., vol. 11, 1939, pp. 334-339.

DISCUSSION

Various methods are suitable for collecting comparative data on the concentration of the significant gaseous contaminants in the atmosphere.

Corresponding methods for particulate matter are much fewer in number and less satisfactory. Before these methods are discussed it may be well to state some of the requirements believed desirable or essential for such methods. The methods should (1) be direct (that is, they should determine the concentration directly in fundamental units such as mass or number of particles per unit volume of air); (2) include an efficient sampling procedure or one in which preferably all, but certainly a known portion, of the material to be determined is collected; (3) use a sample that requires little or no treatment before the determination is made (to reduce the possibility of contamination or loss of material and to reduce time, effort, and expense for the determination); (4) employ a determining procedure with a high and known accuracy and precision; (5) be dependable, versatile, simple, rapid, and inexpensive; and (6) require only readily available equipment. No known method meets all these requirements satisfactorily.

The best procedure for determining the total concentration of solid or nonvolatile dispersoids in nonexplosive atmospheres is probably collection of a sample of the material from a measured volume of air by an electric precipitator in a container weighed on a sensitive balance using a similar container as a tare. Five and preferably 10 milligrams of material should be collected. Check weighings should be made until the two weighings agree within 0.2 milligram. A filter-paper sampling device may serve in potentially explosive atmospheres.

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A corresponding procedure for determining the concentration of certain constituents is to collect a sample of the total dispersoids from a measured volume of air by an electric precipitator and weigh as before; then to determine the amount of the particular constituent present by a suitable chemical, electrochemical, petrographic, spectrographic, or radiographic method.

A procedure for determining the concentration of the total number of particles in a given microscopic size range is collection of a sample from the air by a thermal precipitator and simultaneous determination of the number concentration and size properties by a microprojector.

SUMMARY

The nature and harmful or otherwise objectionable aspects of contaminated atmospheres and of the contaminants are discussed briefly.

The principles upon which the methods for determining the concentration of gaseous contaminants are based and the concentration, composition, and size properties of particulate contaminants are considered.

Suggestions are made for the collection of comparative information on the concentration of atmospheric contaminants, especially the particulate ones.

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